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Local market of solar water heaters in Taiwan: Review and perspectives

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ABSTRACT

For promotion of solar water heaters in Taiwan, incentive programs were first initiated from 1986 to 1991 and re-initiated from 2000 to the present. The subsidies create an economic incentive for the end users and have been rather instrumental at the initial stage of each program but lost their significance thereafter. To analyze the behavior of the major actors in the local market, two questionnaires were developed. One was addressed to sales and distribution agents while the other one consisted of person-to-person interviews with household owners. The market-driven mechanism is a multi-parametric phenomenon. Other than the capital cost and energy price (cost to benefit), architectural type of buildings (or degree of urbanization) and household composition play the major roles in market diffusion.

Contents

1. Introduction

Energy supply and security play a vital role in the national economical development. In Taiwan, energy consumption increased from 37.73 million kiloliters of oil equivalent in 1986 to 114.66 million kiloliters of oil equivalent in 2007. The average annual energy consumption growth rate during this period was about 5.5%. However, Taiwan is a densely populated island with limited land-based energy resources. The ratio of indigenous energy to total energy supply decreased from 10% in 1986 to 1.7% in 2007. In addition, the increasing levels of greenhouse gas CO_2 by burning fossil fuels is creating global warming. To establish a reliable and clean energy supply and demand system, two National Energy Conferences were convened in 1998 and 2005 for the purposes of formulating strategies and measures in response to the impact of the United Nations Framework Convention on Climate Change and to seek a balance among economic development, energy supply, and environmental protection [1].

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Although the intermittent nature of renewable energy resources, they are a sustainable and clean energy asset derived from nature. Other than the net energy saving, the environmental benefits are reduction in the production of air pollutants and release of greenhouse gas into the atmosphere. The major resources include solar energy, wind energy, geothermal energy, ocean energy, biomass, and energy from waste. For the development of indigenous alternative and renewable energy resources, the Taiwanese government initiated subsidy programs on solar water heaters (SWHs), solar photovoltaic systems, resource exploration of geothermal power demonstration systems and energy crop green bus projects. A Renewable Energy Development Bill has been submitted for ratification to establish a legal environment for renewable energy [2]. It is expected renewable energy will number 3% of the primary energy supply by the year of 2020 in Taiwan.

SWH has been proved to be reliable and economical in cases of hot water production, and is also the most successful story for the development of renewable energy in Taiwan [3]. The accumulated area of solar collectors installed at the end of 2007 reached 1.66 million square meters. In this context, Taiwan has a lot of experience in the SWHs market. On the other hand, the local market has been growing at a slower pace over the last few years. Thus, the present study is devoted to an extensive evaluation of the local SWHs market. The time variation of the local market is initially presented. Several questionnaires were evaluated to discuss the perspectives for its further development. This information would be useful for all parties related to this market, manufacturers, potential users and policy makers.

2. Historical SWHs market in Taiwan (1978–2007)

Taiwan began the manufacture of SWHs in 1978, Fig. 1. Over the next 7 years, the SWHs penetration in the local market was gradually rising. The area of solar collectors installed was less than 10,000 m^2 per annum. This is attributed to lower average family income in the early eighties and higher installation cost compared with conventional hot water heaters. In order to encourage the utilization of SWHs, the Taiwanese government initiated a 6-year incentive program (1986–1991). This built up the standard of application for SWHs, in which more useful energy was collected from a solar collector and lower heat loss were required. The manufacturers of SWHs were also motivated by this financial incentive. As a result, the local market expanded dramatically (1986–1988), approaching 60,000 m^2 per annum. Over the next 3 years (1989–1991), the local market was roughly constant. Furthermore, more than 340,000 m^2 of solar collectors were installed through 1992–1995. This would be due to the mature

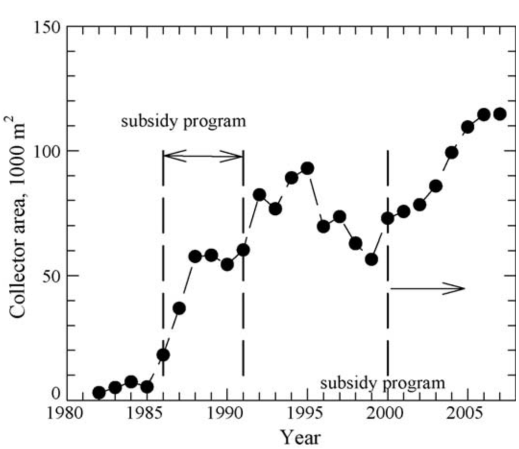


Fig. 1. Annual sales of SWHs in Taiwan.

solar thermal technology, and the rapid economic growth and a subsequent increase in the current receipts and disposable income of each household in this period would be the other key factors in market expansion. More households could afford to purchase SWHs. In addition, Chang et al. [4] indicated popularization of SWHs in Taiwan was strongly coupled with the status of new construction. According to the Construction and Planning Agency of the Ministry of the Interior (CPA, MOI), the construction of new buildings reached a peak in 1994. This corresponds to the peak area of solar collectors installed as shown in Fig. 1. Since 1996 the local market decreased significantly. The annual area of solar collectors installed in 1999 was less than that at the end of the first incentive program (1991). The faltering economy and declining rate of construction of new buildings would play the major role.

To further promote the application of solar thermal energy, the Taiwanese government initiated another incentive program for SWHs (July 2000-present). The subsidy has created an economic incentive for the end users. This results in a strong impact on the popularization of SWHs, Fig. 1. The growth rate was about 29% in 2000 and the area of solar collectors installed was over 100,000 m^2 per annum since 2004. Note that the annual area of solar collectors installed doubled from 1999 to 2006. Thus, the influential incentives for SWHs by the government during the last two decades have boosted the domestic market significantly. Further, it is noted the local market is almost constant in the 2006–2007 period. This might imply the current incentive program has lost momentum in expanding the market. However, the population of residential SWHs today in Taiwan still covers a small percentage of households, and the potential market should be far from saturation point.

3. Summary of SWHs installed (2000–2007)

In the second incentive program, the Bureau of Energy of Ministry of Economic Affairs (BEMOEA) has provided a subsidy to the end users based on the area of solar collectors installed (1500 NTD/m^2). The amount in the remote islands is double, in which the subsidy is up to 24% of the installation cost. In addition, performance of a SWH (e.g. design, installation and after-sale service) is critical to improve its acceptability by the end users. To be eligible for this incentive program, all technicians (installers, dealers and manufacturers) must take some training courses in order to become licensed. With a guideline of system design (tilt angle of solar collector, thermal insulation, shading by neighboring buildings and pipe routing), reliable operation of SWHs has been reported. Furthermore, certification of SWHs was also a prerequisite. There is only one accredited laboratory (Energy and Environment Research Laboratories, Industrial Technology and Research Institute) by BEMOEA for performance testing. From 2000 until now, there were 344 qualified products, 295 qualified installers/dealers, and 40 qualified manufacturers. Note that 95% of qualified installers/dealers are located in western Taiwan.

The National Cheng Kung University Research and Development Foundation has been authorized to organize an operational unit to carry on the tasks of the present incentive program, which include filing and auditing of applications, allocation of the funding, and the appeals process. For each new SWH installed, the end users should provide address and specifications/price of product. This essential information about the system is then statistically analyzed to generate the regional distribution of SWHs in Taiwan. Further, two approaches were applied to investigate the key factors in the local market of SWHs in this work. The desk research is mainly on the collection of the related data from official and other sources, and the field research based on the use of a number of questionnaires has been conducted. Five-hundred SWHs owners each year were approached through person-to-

person interviews. These questionnaires consisted of questions on (a) the attitude towards SWHs; (b) main technical problems; (c) installation location; (d) year of completion of housing construction; (e) household composition.

3.1. Products and applications

For hot water production in the domestic sector, most SWHs use natural circulation. A horizontal storage tank is positioned above the solar collectors, and more than 95% of SWHs had an electrical booster element installed as a backup heating system. The solar collectors used are flat-plate type and evacuated-tube type. Almost all metallic (stainless or copper) flat-plate type solar collectors have been produced domestically while the collectors of evacuated-tube type is imported, in which the average area of solar collector installed of SWHs is 5 m^2 and 3 m^2, respectively. The ratio of volume of storage tank to solar collector area ranges from 50 to 80 l/m^2. The annual sales of SWHs with both types of solar collectors are shown in Fig. 2. The glazed flat-plate type with metal absorbers and glass cover are widely used to transform solar energy into heat. The market share was over 97% in 2001, and the area of solar collectors installed per annum increased almost 50% over the next 3 years. Since 2004 the yearly installation appeared to reach the saturation point, and the market share was in a gradual decline. On the other hand, the annual sales of evacuated-tube type expanded greatly. In 2007 the area of solar collector installed was more than 10,000 m^2, in which the market share approached 10%. The role of international competition might be more important in the near future.

It is very difficult to promote SWHs without governmental support. The Taiwanese government has enforced the improved performance or standards (energy collected and heat loss) on SWHs since the first incentive program. Thus, the product marketability is not solely based on word of mouth and previous experiences with the product rather than actual performance. However, the manufacturing procedure of SWHs does not require advanced technology. Other than the economic nature, technical guarantee/support would be one of the major factors affecting the brand selection. Quality control and cumulative experience of certified technicians are considered to be related to the annual sales of individual manufacturer. In the period of 2001-present, the accumulated area of solar collectors installed in Taiwan was about 657,000 m^2 and the market share of top 10 brands is shown in Fig. 3. Although there are 40 qualified manufacturers, the top ten brands occupy 90% of the local market, particularly the top three (50%). It is also noted the price reduction was observed in the first 4 years within the present incentive program. This is not only related to technical change but also to a systematic effort to reduce costs through economies of scale (or sales increase).

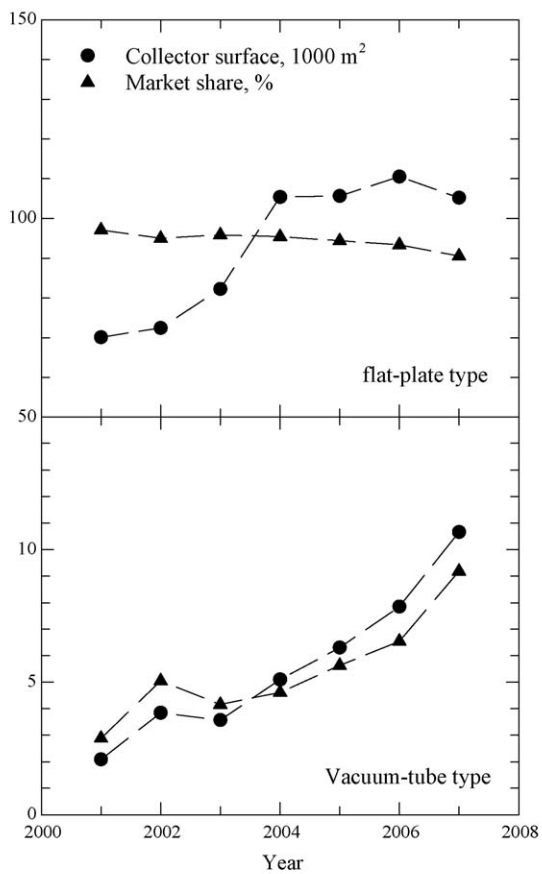


Fig. 2. Annual sales of SWHs with flat-plate or evacuated-tube solar collectors.

3.2. Public attitude towards SWHs

The capital cost of SWHs is considerably higher than that of conventional hot water heaters. Thus, the available family income would be a serious factor in the potential number of households who can invest in SWHs. The monetary benefit accrued to the end users is another concern, which would depend on the amount and cost of fuel saved through the use of SWHs [5–7]. In Taiwan, the accumulated area of solar collectors installed increased significantly in the late eighties, which is partially due to the rapid economic growth and a subsequent increase in the current receipts and disposable income of each household. More households can afford to purchase SWHs [5,8]. Further, Taiwan has strong potential for harnessing solar energy. The payback period was expected to decrease with the improved system design and performance. Thus, with the well-organized and concerted efforts (incentive programs and research projects) taken by the government [9], there is increasing public interest in the domestic sector.

Concerning the public attitude towards SWH applications, a total of 4900 copies of the questionnaire by the end users were completed. It was found there were about 14% of households replacing the old systems. The detailed time-evolution of cumulative SWHs in operation could be evaluated with a more comprehensive market survey in the future. Further, the present survey indicated the relative importance of the various factors according to the opinions of households equipped with a SWH. Households give a greater emphasis to economic factor (energy saving, 56%). This should be attributed to the emergent worldwide energy reserves shortage. On the other hand, hot water heaters

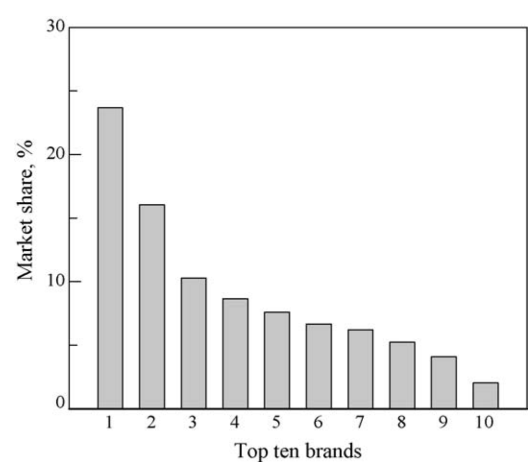


Fig. 3. Market share of top 10 brands, 2001–2007.

Table 1
Application of SWHs (units).

	2001	2002	2003	2004	2005	2006	2007	Total
Homeowner	12,636	14,644	16,479	21,569	22,489	24,223	26,171	138,211
Dormitory	50	45	61	83	93	76	161	569
Others	3	4	8	10	5	9	5	44

using LPG or natural gas are the most popular ones in Taiwan. However, carbon monoxide poisoning was frequently reported in winter, so safety is another concern by the respondents. The opinion of friends and market campaigns (product distribution network) are also appreciated. Finally, households are favorably but not thoroughly influenced by environmental factors, including limitations on greenhouse gas production and sharp environmental deterioration problems. Thus, further promotion campaigns are necessary to educate end users on the socio-cultural benefits of SWH applications.

3.3. Residential SWHs

The use of solar thermal collectors is an economic alternative for hot water production in Taiwan. In view of the current governmental-supported financial incentives to end users, there were 138,824 units installed in the period of 2001–2007, Table 1. The yearly installation increases continuously. However, the applications for dormitories and others (swimming pools or manufacturing plants) are rather limited. It is also known the system design and capital cost of SWHs are related to the composition of the families. According to the historical data of average daily global solar insolation in Taiwan, the daily production of 50 °C hot water by solar collectors is estimated to be 75 l/m^2. On the other hand, the average consumption of 50 °C hot water is about 60 l/person. In Fig. 4, it can be seen that less than 1% of SWH users are one-person households. The family size of 4–6 persons is more positive in installing a SWH (nearly two-third of the users). Larger SWH systems designed for more than 9 persons accounted for 11.25% in the SWH user composition. Further, the data of SWH installation in terms of solar collector area is shown in Table 2. Most systems (82–88%) had an area of solar collector installed from 3 to 10 m^2. This agrees with the household structure of SWH users. The market survey also indicated the share of evacuated-tube type solar collector expanded greatly recently and its average installed area was less than that of flat-plate type. This should be attributed to more systems with the installed area less than 3 m^2. However for economic concerns, larger scale applications would benefit from the effect of scale. The unit price of both

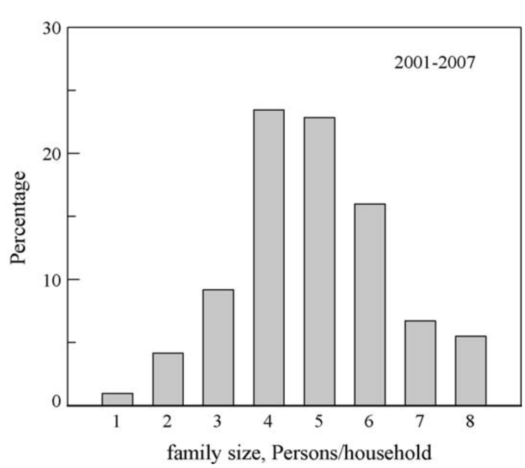


Fig. 4. Household structure of SWH users.

types of solar collectors is shown in Table 3. It can be seen the unit price of a SWH decreases with larger area of solar collectors installed, particularly with flat-plate type solar collectors. Compared with smaller SWHs for one-person households (below 3 m^2), the unit installation cost in a larger scale system ($A_c > 5$ m^2) can be cut in half and payback period is expected to decrease.

The questionnaire indicated there were about 14% households replacing the old systems, and the service life ranged from 5 to 15 years. In terms of service life of 15 years, the current operating SWHs are estimated to be 260,000 systems. According to the data of Directorate General of Budget Accounting and Statistics (DGBAS) [10], the number of households in 2007 was about 7.5 million in Taiwan. This indicates the popularization of residual SWHs might be only up to 3.5%, which represents only a small fraction of households. This is also far away from the target for the year 2020 with 20% households equipped with a SWH [1]. However, it is known the potential market of SWHs could be related to the construction of new buildings, household structures and available installation locations. Thus to be more realistic, the potential households with a SWH should be estimated based on the above factors. Then policy makers can organize systematic efforts in order to achieve the target.

3.4. Regional distribution of sales

Through the questionnaires used in this work, local climatic conditions and degree of urbanization are among the dominant factors on the regional distribution of sales. Taiwan is situated between latitude 22° and 25° North, which measures 377 km long and 142 km wide at its widest point, Fig. 5. About two-thirds of the island is covered with lush forested mountains [11]. During the period of 2004–2007, the average annual duration of sunshine at eight representative locations (five in the western district and three in the eastern district) ranged from 1450 to 2400 h, as shown in Fig. 6. This corresponds to the average daily global solar insolation of about 3.25 kWh/m^2 in the north and 4.64 kWh/m^2 in the south [12]. However, it is known hot water consumption is expected to be the highest in winter and the lowest in summer. In Taipei, Ilan and Hualien, the winter months received less than 100 h of sunshine. This essentially results in less energy saving and a longer payback period. The impact of typhoons is another concern for the home owners who install SWHs in eastern Taiwan (Ilan, Hualien and Taitung) [13]. In addition, almost all SWHs in Taiwan are positioned on the roofs of buildings (flat roofs or tilted roofs). Thus, the degree of urbanization may not allow easily the implementation of SWHs. According to DGBAS [10], there are five main urban areas (more than one million residents: Taipei,

Table 2
Installation of SWHs in terms of area of solar collector.

A_c (m^2)	Below 3	3–5	5–10	10–100	Above 100	Total
2001	1192	5,504	5880	277	8	12,861
2002	1979	6,236	6342	321	6	14,884
2003	2114	7,310	7176	352	4	16,956
2004	2983	9,220	9409	349	9	21,970
2005	3227	9,688	9581	326	8	22,830
2006	3988	10,468	9913	303	12	24,684
2007	4174	11,134	8980	354	4	24,646

Table 3
Unit price in terms of solar collector area (NT$/m^2).

A_c (m^2)	Below 3	3–5	5–10	10–100	Above 100
Flat plate	12,527	8659	6181	6870	7003
Evacuated tube	8,726	7420	6932		

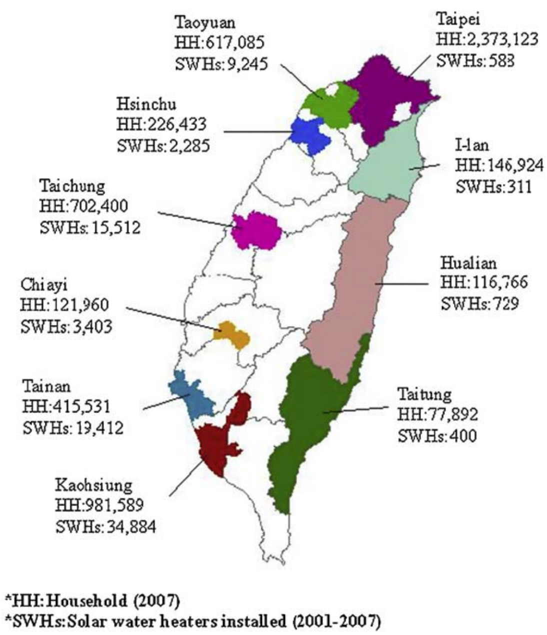


Fig. 5. Regional distribution of sales.

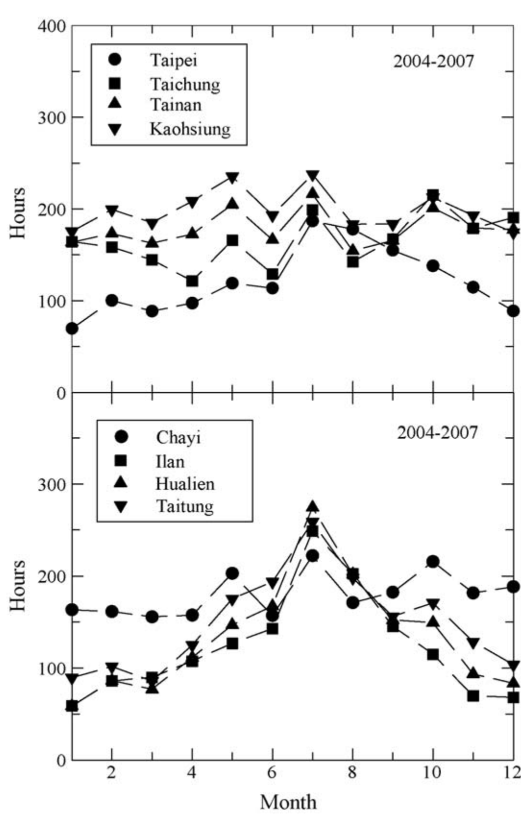


Fig. 6. Duration of sunshine.

Table 4
Number of households (2007) and SWHs installed (2001–2007).

	Household	SWH units	Popularization	A_c (m^2)	Market share (%)
Taipei	2,373,123	588	0.25	4,087	0.62
Taoyuan	617,085	9,245	14.98	56,665	8.63
Taichung	702,400	15,512	22.08	81,198	12.36
Tainan	415,531	19,412	46.72	96,515	14.69
Kaohsiung	981,589	34,884	35.53	151,076	23.00
Hsinchu	226,433	2,285	10.09	15,979	2.43
Chiayi	121,960	3,403	27.90	15,961	2.43
Ilan	146,924	311	2.12	1,463	0.22
Hualien	116,766	729	6.24	5,689	0.87
Taitung	77,892	400	5.13	2,219	0.34
Others	1,732,746	44,204	25.51	225,961	34.40

Popularization: units of SWHs installed per thousand households.

Taoyuan, Taichung, Tainan and Kaohsiung) and two secondary urban areas (0.3–1 million residents: Hsinchu and Chiayi) in Taiwan. In 2007, over 70%of the resident population lived in those urban areas. Installation of SWHs would depend on the architectural types in each area.

Due to the sunlight conditions, the SWHs installed in northern Taiwan (Taipei, Ilan, Taoyuan and Hsinchu) are expected to be lower than those in the western and southern districts. As shown in Table 4, the number of households was about 2.37 million in the Taipei urban area (2007). This corresponded to 31.5% of the total households in Taiwan. However, there were only 588 SWHs installed over the period of 2001–2007, in which the accumulated area of solar collectors was 4087 m^2 and the units of SWHs installed per thousand households was only 0.25. Additionally, limited SWHs (311 units) were installed in Ilan. In Taoyuan and Hsinchu, the popularization of SWHs (less than 15 units per thousand households) was less than that of rural area (over 25 units per thousand households, not including the eastern district). In southern Taiwan, the market share was over 55%. The popularization is the highest in Tainan urban area while the area of solar collectors installed was over 150 thousand square meters in Kaohsiung. Furthermore, it should be noted the average daily global solar insolation in Taitung was roughly the same as that in Taichung. However, the popularization is only about one-fourth. This might be attributed to the average income level of households and typhoon impact.

4. Future prospects

Wu and Huang [2] indicated rapid passage of the Renewable Energy Development Bill as a key factor in expanding the market for renewable energy in Taiwan. Related policies, as well as legal and institutional support measures (related to architectural laws, green procurement laws) must also strive to facilitate the sustainable utilization of renewable energy. For SWHs, there were over 97% systems for domestic hot water production. Economic aspects (capital cost of SWHs and energy price index) would be the other major concern [4]. The potential market is also considered to be attributed to available installation location (ownership, architectural type of buildings and degree of urbanization) and household composition. Using the desk research (collection of the related data from official and other sources) and the field research (a number of questionnaires) since 2000, those issues are addressed as below for future promotion of SWH applications in Taiwan.

4.1. Economic aspects

Other than the technical problems faced by SWH users, the economic viability and attractiveness of a SWH could be based on the system payback period in comparison with the expected

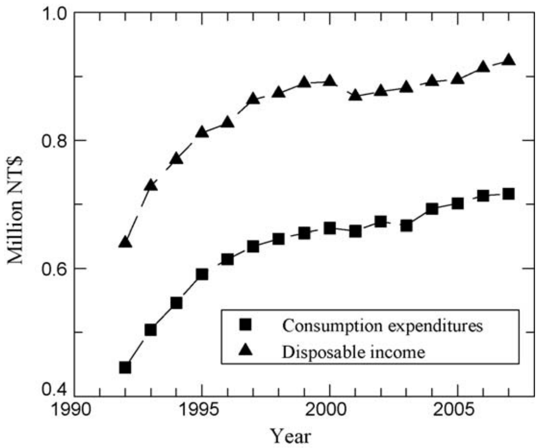


Fig. 7. Average family income and expenditure per household.

service life of the installation [7]. It is known the payback period is associated with solar insolation, duration of sunshine, energy price and hot water consumption. A quick estimation by Industrial Technology and Research Institute indicated the payback period of SWHs in Taiwan was about 5–6 years. However, it might be underestimated in the northern district with lower solar insolation. High oil prices in recent years would be another dominant factor. Sidiras and Koukios [14] further pointed out one of major diffusion barriers in the case of households might be due to other investment priorities. It is thought the cost of SWHs should be less than a specific fraction of family income. Thus, the household might be willing to invest in the purchase of a SWH. In Fig. 7, it can be seen both average family disposal income and consumption expenditures (food, rent and water charge, health care and medical, transportation and communication, recreation and education, etc.) increased significantly in the early nineties followed by a mild increment. However, average saving (difference between disposal income and consumption expenditures) was roughly the same since 1992. Thus, it can be expected the household might have less motivation to install a SWH on the basis of pure financial criteria. In addition, average saving in the rural area appeared to be less than that in the urban area. This might partially correspond to lower popularization of SWHs in Ilan or Hualien as shown in Table 4.

It is widely recognized economic instruments play a key role in the promotion of renewable energy sources worldwide [5,15,16]. In Taiwan, a subsidy for the purchase of a SWH was apparently effective in popularization of residential SWHs at the initial stage of each incentive program but lost its significance thereafter [4]. However, the development and use of renewable energy sources and technologies are still vital for the management of energy supply and demand in Taiwan. In expanding the market, BEMOEA proposed a revised incentive program recently. The subsidy to the end users based on the area of solar collectors installed will be 50% more (from 1500 NTD/m^2 to 2250 NTD/m^2). In terms of subsidy to capital cost of a SWH, the ratio would range from 18 to 36% for a residential SWH. Further, Kaohsiung city government announced another local incentive program in October, 2008. An additional subsidy of 1500 NTD/m^2 in purchase of a SWH will be granted to the households living in the city. Thus, sales expansion could be expected in the near future. Note that the uncontrollable oil price is expected to be another driving force to affect the market demand for SWHs.

4.2. Available installation location

It is thought the ownership and architectural type of buildings might limit the available area for SWHs installation. According to the housing census in 2000 (the next census will be conducted in 2010), the total number of housing units was near 7 million in Taiwan. The average vacancy rate was 17.62%, which represented more than 1.2 million vacant houses. The detailed regional distribution of housing units is shown in Table 5. The vacancy rate is the lowest in Taipei among the urban areas. As mentioned above, the number of households in Taipei urban area was about 31.5% of the total households in Taiwan. A lower vacancy rate is attributed to higher population density (persons per square kilometer). In the eastern district (Ilan, Hualien and Taitung), the vacancy rate (18.66–22.46%) is considerably higher than that of other rural areas (15.22%). Further, a survey by CPA, MOI in 2006 indicated the total housing units was over 7.4 million and the house ownership was 83.9%. The average vacant rate dropped to13.9%, which corresponds to more than one million vacant houses. In particular, the vacancy rate in the Taoyuan urban area decreased from 23.24 to 12.5%. This is considered due to the change of population distribution in the Taipei and Taoyuan urban areas [4]. In Ilan, the vacancy rate also dropped to 12.2%, which might be due to the construction of National Highway 5 from Taipei to Ilan. However, the vacancy rate was the highest in Hualien, which was up to 37.7%.

Other than the regional distribution of housing units, architectural type of buildings is the major concern for available installation location of SWHs in Taiwan. According to DGBAS [10], the share by style of building is shown in Fig. 8. It can be seen there was an increasing trend in the sharing of two- or three-story

Table 5
Census of house in 2000.

Region	Housing unit	Vacant house	Vacancy rate
Taipei	2,222,153	353,741	15.92
Taoyuan	570,538	132,615	23.24
Taichung	724,827	161,480	22.28
Tainan	395,565	70,211	17.75
Kaohsiung	869,195	146,155	16.82
Hsinchu	202,942	36,601	18.04
Chiayi	120,662	23,863	19.78
Ilan	140,408	30,749	21.90
Hualien	111,128	24,959	22.46
Taitung	68,368	12,757	18.66
Others	1,549,301	235,876	15.22
Sum	6,975,087	1,229,007	17.62

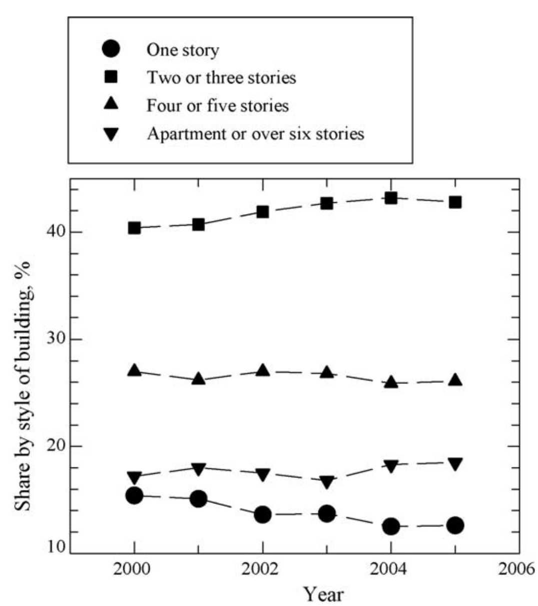


Fig. 8. Share by style of building.

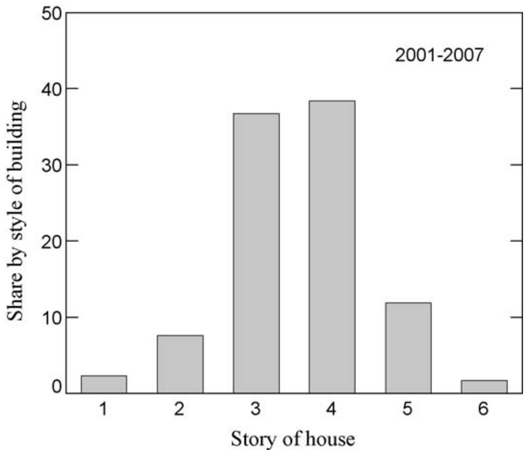


Fig. 9. Style of building with SWH installed.

houses from 2000 (40.4%) to 2005 (42.8%). The share of one-story houses showed an opposite trend, which went from 15.4 to 12.6%. The apartments or over six-story houses accounted for about 17.7%. Moreover, the results of household questionnaires indicated over 81% of SWHs were positioned on the flat roof of building and the tilted roof took 12% of sales. In terms of style of building, Fig. 9, three- and four-story houses took 36.4 and 38.4% of SWHs installed, respectively. The market share of one-story or over six-story houses was less than 4%. Chang et al. [4] indicated apartments and group housing are the major types of housing in Taipei urban area (over 75%). If related architectural laws were not amended toward the installation of SWHs, it would be difficult to install a stand alone SWH in those types of buildings.

4.3. Household structure

One-person households have stood at the highest level among the total households in Taiwan. In Fig. 10a, it can be seen the share of one-person households increased from 23.4 to 26.9% over the past 7 years. This phenomenon might be due to outflow of employed population, schooling population or marital status such as the unmarried [10]. The average size of households has also decreased in Taiwan as the social environment has undergone rapid change, and the composition of the household tends to be simplified. In Fig. 10b, the two-person to four-person households, which correspond to nuclear family households (a married couple, a married couple with their unmarried children or single parents with unmarried children), dominated the household composition in 2007 and stood at 53.5%. The households with six persons or more only accounted for less than 10%. Further, the composition of family with a SWH is shown in Fig. 10b for comparison. The four-person to six-person households are known to be more positive in installing a SWH (nearly two-third of the users within the 2001–2007 incentive period), and there are nearly 5% of SWHs for the one-person and two-person households. As mentioned in Section 3.3, this might be due to decreasing unit price and subsequent shorter payback period with larger area of solar collectors installed. However in comparison with the household composition, one-person and two-person households stood at nearly 45% of total households. Thus, the size of family or household composition should be added to the list of critical factors in marketing campaigns and policy-making process for long-term SWHs diffusion in Taiwan.

4.4. Potential market

Taiwan with a 110,000 m^2 annual installation area of solar collectors ranks among the top 10 SWH markets in the world, and the accumulated installation area was over 1.66 million square meters in 2007. However, the popularization of residential SWHs in terms of total households is estimated to be only 3.5%. The remaining households use electrical or gas heaters for hot water production. The target of BEMOEA for the year of 2025 is 4.09 million square meters in accumulated installation area. In order to achieve this, 540,000 additional systems have to be installed during the coming 17 years (about 32,000 systems per annum). With increasing public awareness on environmental benefits and energy saving, the authors believe the aim is realistic even without any economic incentives.

Other than at the initial stage of two incentive programs, Chang et al. [4] pointed out the annual area of solar collectors installed in Taiwan is coupled with total floor area of new buildings reasonably well. The technical problems like pipe routing and higher installation cost for residents of older houses might be the other major barrier for SWH installation. Furthermore, the present study shows the apparent trend of architectural type (available installation location) and household composition on popularization of SWHs in Taiwan. In the Taipei urban area, apartment and group housing are the major types of housing. Space is a limiting factor on the potential number of households using SWHs, and the popularization of SWHs was only 0.25 per thousand households. It is considered that sharing of hot water resources among the building residents is possible only when government regulation is implemented forcing builders to incorporate centralized SWHs in the building design. Also shown in Table 4, Ilan has the lowest popularization of SWHs (2.12 per thousand households). Lower duration of sunshine as shown in Fig. 6 and average saving per household would be the major concerns. Furthermore, the number of households in the Taipei urban area and Ilan was over 2.52

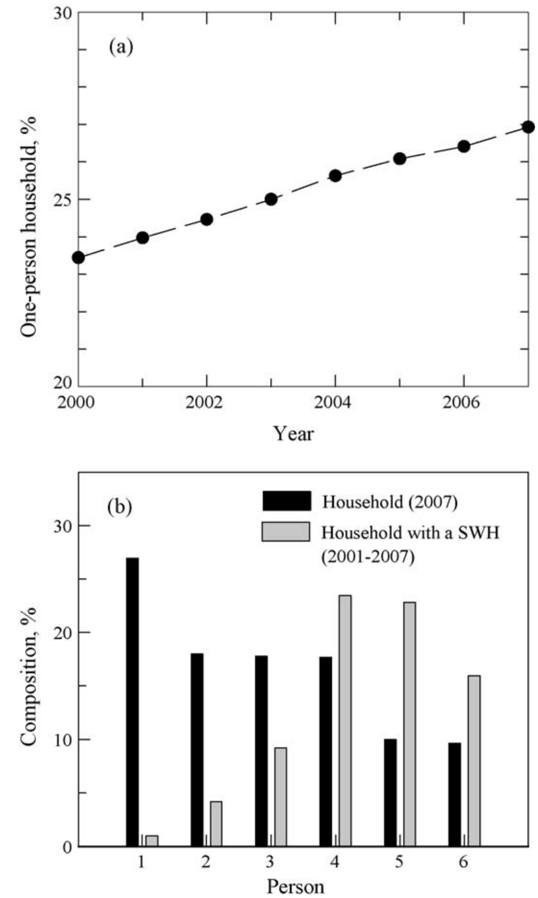


Fig. 10. Composition of the families.

million. This means that there might be over one-third of households in Taiwan with limited potential applications of SWHs. In the Kaohsiung urban area, apartment and group housing also accounted for nearly 40% of total housing units [10], which corresponded to 0.35 million households. Further, on account of installation costs, the survey of SWH users indicated that one-person and two-person households accounted only 0.96 and 4.16%, respectively. Thus, household composition would be another major barrier for possible SWH applications. Other than Taipei/Kaohsiung urban areas and Ilan, one-person and two-person households are estimated to be 24.9% (1.09 million households) and 17.5% (0.76 million households) of households in 2007, respectively.

According to DGBAS, housing units and number of households were roughly the same. However, the average vacancy rate was up to13.9% and the house ownership was 83.9% in 2006. To get a quick estimation of potential SWH market in Taiwan, it would be reasonable to assume that the major barriers for households are architectural type of buildings (Taipei/Kaohsiung urban areas) and household composition (one-person households). Thus from the above analysis, the possible potential SWHs installed in Taiwan is estimated to be only 3.52 million households. In other words, the current popularization of residential SWHs should be about 7.4%. Note that the target of BEMOEA for the year of 2025 is 4.09 million square meters in accumulated installation area (or 540,000 new systems during the coming 17 years). With a service life of 15–20 years and the same characteristics of household structure, there could be 15% of potential SWH users equipped with a SWH. However, the revised incentive program could be expected to increase the economic attractiveness of SWHs and boost the market.

5. Conclusions

SWH is a very reliable and mature technology, and is the most successful story for the development of renewable energy in Taiwan. Public awareness on energy saving and environmental aspects is also very positive. However, the use of SWHs for domestic hot water production represented only a small fraction of the potential applications of this technology. Through desk and field research, the major diffusion barriers for households are economic nature (disposal income and incentives), population characteristics (household composition), degree of urbanization (available installation location) and climatic conditions (solar insolation, typhoon, etc.). Therefore, there are some recommendations on SWH applications as follows.

- From the geographical point of view, Taiwan is an ideal location to take advantage of solar thermal energy technology. The phenomenon of impressive SWHs diffusion is due to public awareness, product standardization and incentive programs. However, economic feasibility in terms of family income, installation cost and payback period should still play the major role in future market campaigns. A systematic effort could be made to reduce costs through economies of scale (sales increase).
- Government subsidy is apparently effective only at the initial stage of each incentive program. Other than non-economic factors, new regulations and dynamic incentive programs at the regional level would be more important to boost the market in the domestic sector.
- The degree of urbanization of the major Taiwan cities does not facilitate the application of SWHs. Exploration of market in apartment and group housing (i.e. centralized SWHs) needs to be addressed.
- Although the unit installation cost can be cut in half for larger scale systems, there are over 97% SWHs for hot water production in the domestic sector. However, the variation of oil, LPG and natural gas prices creates a favorable environment for SWHs in industrial applications. Upgrading of advertising campaigns is necessary to demonstrate the use of large-scale SWHs (i.e. manufacturing plants).
- The accumulated area of solar collector installed could possibly reach the BEMOEA target of 4.09 million square meters by the year 2025. However, the target of 20% households equipped with a SWH is not realistic. Based on the present analysis, the potential SWH users will be less than half of the households in Taiwan. Taking the aging effect into account, the popularization in terms of potential SWH users would be more than 15% in 2025. The market is still far from the saturation point.

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